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Routes to interchange mode turbulence and chaos in plasmas confined by a helical magnetic field

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The work is based on experiments performed in a laboratory plasma confined by a helical magnetic field [1], i.e. a toroidal plasma with a weak vertical magnetic field superposed on a purely toroidal field. Using the magnetic field strength B as a control parameter in a hot-cathode produced helical plasma, it is demonstrated that there is a threshold B_T for electrostatic flute interchange modes ($k_{||}=0$) on the low B-field side of density maximum. This is really a threshold in the gradient of the electron pressure profile, since this profile is controlled by the magnetic field in the steady flow state appearing for $B<B_T$.

For $B>B_T$ radial profiles of electron pressure are exponential on both sides, but on the low field side the scale-length approaches a constant value as B is increased. The formation of this resilient profile occurs as power spectra of electrostatic fluctuations evolve from purely monochromatic at threshold, via a period doubling route to turbulence when $B \gg B_T$. The helical magnetic field lines introduce a periodicity condition for the flute modes in the vertical direction, locking the wave-number to $k_V = B_T/RB_V$ or its higher harmonics. This corresponds to a mode coiled up like a snake.

In the long wave-length approxmation the unstable flute modes take the form of purely growing convection cells where the spatial density and potential oscillation are 90^O out of phase, giving rise to radial plasma transport. If the back-reaction of this anomalous transport on the density profile is taken into account, a closed model of three autonomous first order ordinary differential equations can be formulated, which is very similar to the celebrated Lorenz model [2,3] for atmospheric convection. Qualitatively this model describes the period doubling route to chaos observed experimentally, but the long wave-length limit is inconsistent close to instability threshold where the dynamics take place, and predicts an incorrect threshold. The remedy of this situation requires a more complicated model requiring five equations. Work along these lines are presented and compared to experimental results.

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